The Importance of Protocol Simulations during Standards Development

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Abstract

In the past as wired network technologies advanced in data rate and distance per link, the error rate on those links declined. Thus allowing new protocols the freedom to concentrate on tasks other than error correction, retransmission, and data recovery or to use lighter-weight protocols. However with the continued growth of wireless network technologies into the main stream, error rates again are high and protocols now must scrutinize the protocols for error detection, recovery functionality, and robustness in such hostile environments. Protocols developed for these conditions must be completely specified for all contingencies. This requirement means that the protocols being standardized must be thoroughly verified before the standard is complete.

Most simulations for wireless networks are done based on error rates and data throughput because they are concerned strictly with performance. Few, if any, examine the protocol itself for proper operation. The protocol's behavior is even more important under wireless conditions, especially for "hanging" situations, such as dead- or live-locks, which can easily occur.

This paper covers the past and present experiences of using protocol simulations during standards development within the Institute of Electronics and Electrical Engineers (IEEE) 802 working group 15. The protocol simulations cover the overall behavior of the medium access control (MAC) sublayer and physical layer functions. The protocol simulations are modeled using the Specification and Description Language (SDL) (ITU-T Recommendation Z.100) and simulated using the Telelogic Tau Software Suite.

Keywords

behavior, IEEE802.15.4, protocol, simulation, SDL, testing

Introduction

The IEEE 802 has long been involved with developing protocols for local area networks (LANs) and metropolitan area networks (MANs). They began work on wireless local area networks (WLANs) with the establishment of the 802.11 working group. Later they began work on wireless personal area networks (WPANs) with the establishment of the 802.15 working group. As part of the IEEE 802.11 standard for WLAN, the first formal description of the protocol using the specification and description language (SDL) was produced. Even though this model came after the final approval of the standard, it was still useful. It provided the first glimpse for most IEEE members into a larger world of the SDL language and its usefulness in creating and specifying standards. Some members of the WPAN working group recognized the usefulness of the SDL models and requested that one to be created for its, then draft, IEEE 802.15.1 standard. Now, two other SDL models are underdevelopment, one for each of the other drafts: 802.15.3 and 802.15.4.

This paper will cover the current work for creating and completing the SDL for the 802.15.4 draft standard. Where lessons learned from the creation of the SDL for the draft 802.15.1 standard are relevant, they too will be covered.

Even though the SDL models for the 802.15 drafts are considered informative, not normative, as was the case for the IEEE 802.11 SDLs, this work is critical to the creation and understanding of the protocols being defined. Also, it provides an opportunity to test and, if necessary, modify the protocol before it becomes final.

TG4

The draft 802.15.4 standard for wireless medium access control (MAC) and physical layer (PHY) specifications for low rate wireless personal area networks (LR-WPANs) targets a specific area of applications where currently available wireless technologies are overkill. The specific area of application is for devices requiring low data rates over short distances where power consumption is at a minimum. For LR-WPAN's application in the home environment, see [Callaway].

The 802.15.4 draft standard defines a physical layer that covers three different frequency bands and multiple data rates along with their modulation techniques. The maximum data rate is 250 kbit/s. The function is to transmit and receive data and provide management controls.

The MAC covers the means by which devices will access, share, and communicate with other. The medium may be shared through a peer mechanism, CSMA/CA, or may be dedicated to guarantee access. The communication between at least two devices in a single coverage area is called a personal area network (PAN).

Opportunity

Creating and simulating the SDL models for a protocol either begins after the protocol is mature, or in its infancy. During its infancy is the most appropriate time to invest in the SDL development because it allows one to simulate the protocol as it matures. This provides the well needed assurance that what is being suggested works and works as expected. It also allows for simulation of competing proposals for comparisons. This rarely happens, however, as most developers do not have access to an SDL editor or simulation tool. Most of the time, the SDLs are created closer to the maturity date of the draft standard. This requires a lot more immediate effort to write the entire SDL to match the text prose description. For the most part this is an overwhelming task because one is rushing to create and simulate the protocol during one of its final review cycles (e.g. letter ballot cycles). For the IEEE 802 this is usually 40 days or less.

This is the case of the SDL model for the draft 802.15.4 standard. The draft 802.15.4 standard went out for a 40-day letter ballot and an SDL model was started at that time. The SDL model was submitted as part of the comment to the working group letter ballot. However, due to the numerous comments at the close of the first letter ballot period, a completely new SDL model needed to be created. This was done during the time between the completion of the letter ballot comment resolution and the start of a re-circulation of the revised draft 802.15.4 standard. During this re-circulation letter ballot period, this time only 20 days, another SDL model was created and simulated. As the draft reaches maturity the amount of changes to it, as well as the SDL model, should decrease. This would allow one devote more time to testing and simulating various scenarios.

Overview of the SDL Model

The SDL model consists of three SDL packages (signal_definitions, Phy_package, and MAC_package). Packages are used to simplify reuse. This is shown in Figure 1. The signal_definitions package contains the primitives (i.e., signals), and globally used type declarations. The Phy_package contains the SDL block diagram for the physical layer. The lower level interface to this block is the radio interface (i.e., the transmission and reception of physical packets. The upper level interface contains two service access points (SAP). The MAC_package contains the SDL block diagram for the MAC sublayer. The lower level SAPs of the MAC sublayer block match those of the physical layer block's upper level SAPs. The MAC sublayer block has two upper level SAPs, as well.

These packages are used in various SDL systems. Two of these SDL systems are shown in Figure 2 and Figure 3. These two along with other SDL systems are used in the different test scenarios described later.

Simulations

Any model is created to represent a simplified view of something much larger. What one wants to model and thus simulate is only the beginning. Here the behaviors of the MAC sublayer's and physical layers' protocols are modeled and simulated.

Assumptions

The assumptions for simulating any protocol are as important as the protocol itself. For the draft IEEE 802.15.4 standard the assumption was that only the high level behavior would be described and simulated. This means that the exact coding of the Protocol Data Units (PDUs) are not required, real time (system clock) is not necessary, and encoding of the radio frequency is unimportant.

The information contained in a PDU and used by the MAC sublayer or Physical layer is modeled. The exact bit encodings are not. Only the information is conveyed. This simplifies many other items, for example MAC frame Cyclic Redundancy Check (CRC). Instead of coding, decoding, and calculating the CRC, the only behavior is of concern. There are only two outcomes for a CRC. Either the CRC calculation passes or fails. The cases when the CRC passed includes a MAC frame that is correct, found to be in error and corrected, or in error and undetected. When an error was found and could not be corrected, the CRC failed.

Test scenarios

Testing of the SDL models include, syntax checking, simulation, and validation in that order. If the SDL model does not pass syntax checking, then one is not using the SDL properly. This must be corrected before any of the other tests are possible. Once the SDL model passes syntax checking, one knows that it is using the SDL correctly.

Syntax checking does not imply that the SDL model behaves as expected. This is accomplished using the software tool's, Telelogic Tau, built-in feature for simulating an SDL model. Simulating the SDL protocol model requires many steps. The current 802.15.4 SDL model consists of two SDL blocks, one for the MAC sublayer and one for the Physical layer. Simulation testing is applied to each block individually. This will be called single block testing. Single block testing allows one to control the block under study through the use of the service access point (SAP) primitives defined in the protocol. One can exercise every primitive, set any state or variables, and monitor the status. When single block testing is done, the behavior is shown to be as expected. Next the single block (peer-to-peer) testing is performed. This consists of duplicating a single SDL block and connecting them with a communication channel. This type of testing provides the behavior testing as seen in a peered environment. Control in the single block (peer-to-peer) is from the upper layer SAP. When this testing is complete, one understands the interaction of a peer device for this block. After these two model SDL blocks pass the single block and single block (peer-to-peer) testing, one can begin multi-layer testing. Multi-layer testing tests the combination of the MAC sublayer and Physical layer SDL blocks. The SDL system model used in the multi-layer testing is shown in Figure 2. Control in this environment is at the lower level of the physical layer and the upper layer of the MAC sublayer. The results of this type of testing shows the inter-relations and -actions between the two blocks. When this multi-layer testing is complete, one has confidence that the protocols are behaving as expected as a whole system. Next the multi-layer (peer-to-peer) testing is performed by duplicating the two layer SDL block model and connecting them with a communication channel. The SDL system used for the multi-layer (peer-to-peer) testing is shown in Figure 3. This simulation is the last for simulating the majority of the protocols' functions. Since this is a wireless networking protocol, where multiple systems can access the transmissions over the air, there are two more tests that should be conducted. They are the single block (many peers) and the multi-layer (many peers). In these tests multiple duplicates of either a single block SDL model or a multi-layer block SDL model are connected with a broadcast channel. This broadcast channel will simulate the transmission from one device (SDL block) to many receiving devices (multiple and identical SDL blocks). For testing purposes the number of duplicate SDL blocks is three. More may be required to test the capacity of the protocols, but for the purposes stated, three is sufficient.

For each of the six simulation tests one should also do a protocol validation. This is not part of the SDL, but is another feature of the SDL editing software tool. The results of the validation tests should be examined closely. One is looking for dead code, dead- or live-locks, or unexpected conditions. When looking at a single block validation all of the behavior may be executed (i.e., covered). However, this may change when another layer is added, as in the multi-layer block testing. Some behavior may no longer be accessible. This is not a mistake or error, but should be well understood and documented.

Measurement criteria

The measurement criteria for the behavior SDL models are the passage of the syntax checking, observing that the behavior of the SDL model follows the behavior described in the text version of the draft standard, and finally the non-existence of any dead- or live-locks in the validation. The observations of the behavior are subjective, as is the validation, since it is not exhaustive.

Collected data

The collected data are the inconsistencies in naming states and variables, behavioral oddities or by products, alignment of primitives and parameters between layers, and understanding unwritten consequences. All of these have been submitted to TG4 as part of the development and letter ballot process.

Expectations

The expectations are that the SDL will describe the entire behavior of the prose description, demonstrate that the protocol behaves as describe and under assumed conditions, and discover the short-comings, if any, in the protocol(s).

Other expectations may include the expansion of the behavior SDL into a fully coded SDL, which can be used as a source for conversion into a programming language, or a testing language (e.g., Tree and Tabular Combined Notation (TTCN)). These two expectations require a lot more resources than usually can be provided on a volunteer basis.

Conclusions

Simulations are always a simplification of a larger problem, where only one or a few items are under close examination. This permits a better understanding of that particular item under observation, but does not cover the whole. Simulations are most useful when they clearly describe the assumptions, test scenarios, measurement criteria, collected data, and the expectations. Simulation of the protocols under development is useful, if they are timely, complete, understood, and accepted. In many cases simulations are the basis for the decisions for including or not including parts of a standard.

Simulations for examining the behavior of the protocols is as important as the simulations for the wireless environment for which a protocol is intended. Simulating a protocol’s behavior written in SDL is simplified using the Telelogic Tau Software Suite. However the acceptance of the SDL behavior models simulated as complete enough to be equal to the protocol’s prose description within the developing standard is always contested.

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